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Isotope studies of human remains from Mayutian, Yunnan Province, China

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ABSTRACT

In order to examine human mobility during the first millennium BC in the Red River region of Southeast Asia, we examine strontium and stable isotopes in human dental enamel from the Mayutian site. We here report the initial results from this area. Local individuals have $^{87}Sr/^{86}Sr$ values of 0.7096 ± 0.0003. The highest status individual of Mayutian is distinctly different (0.7066) suggesting a geographic origin further northwest, possibly near Dali. Stable isotopes reveal a mixture of C3 and C4 resources in the diet and indicate that they did not have an agricultural strategy that was dominated by either millet or rice.

1. Introduction

Mayutian is located in southern Yunnan on the north bank of the Yuanjiang section of the Red River (Fig. 1). Discovered in 2006 and excavated by the Yunnan Provincial Institute of Culture Relics and Archaeology et al. (2013), Mayutian is the first Bronze Age site to be recognized in this region of Yunnan (Yunnan Provincial Institute of Culture Relics and Archaeology et al., 2013).

The site is unusual in that there are well-preserved human remains, which have been dated through ^{14}C analyses of collagen to the fifth through fourth centuries BC. Because of acidic soils in the Yuanjiang River region, human remains are rare at archaeological sites, but at Mayutian, apparently due to the dryness of the soils, burials of 16 Bronze Age individuals (#M6–#M21) were found.

The Bronze Age burials (Fig. 2), located together 65 m from the main residential area, are in rectangular vertical shaft pit tombs with predominantly northwest/southeast orientations. Burials are in extended supine positions and without burial furniture. Tomb offerings include a bronze *yue*, bronze spear points, a bronze hoe, and ceramic vessels and fragments of stone implements similar to those in the residential area (Table 1).

Artifact assemblages resemble those from contemporary sites in highland Yunnan, and suggest interaction not only with neighboring Dong-Son and nascent Dian cultures but also possibly with the Early Warring States of central China (Yunnan Provincial Institute of Culture Relics and Archaeology et al., 2013).

Because of the possibility of significant cultural interactions beyond the Yuanjiang region, we undertook isotopic analyses of teeth from these burials in an initial attempt to assess mobility among the individuals as well as to begin to develop an isotope database for the region.

We also have a particular interest in comparing the isotope patterns in this region with gender and status. Except for some Mayutian burials that are questionably male, identification by sex was not adequate for such a study, but burial goods (Table 1) indicate one relatively high status individual, GMM12 (Fig. 3).

2. Method

To assess mobility at Mayutian, we analyzed isotopes of strontium, oxygen and carbon of tooth enamel and strontium in bone.

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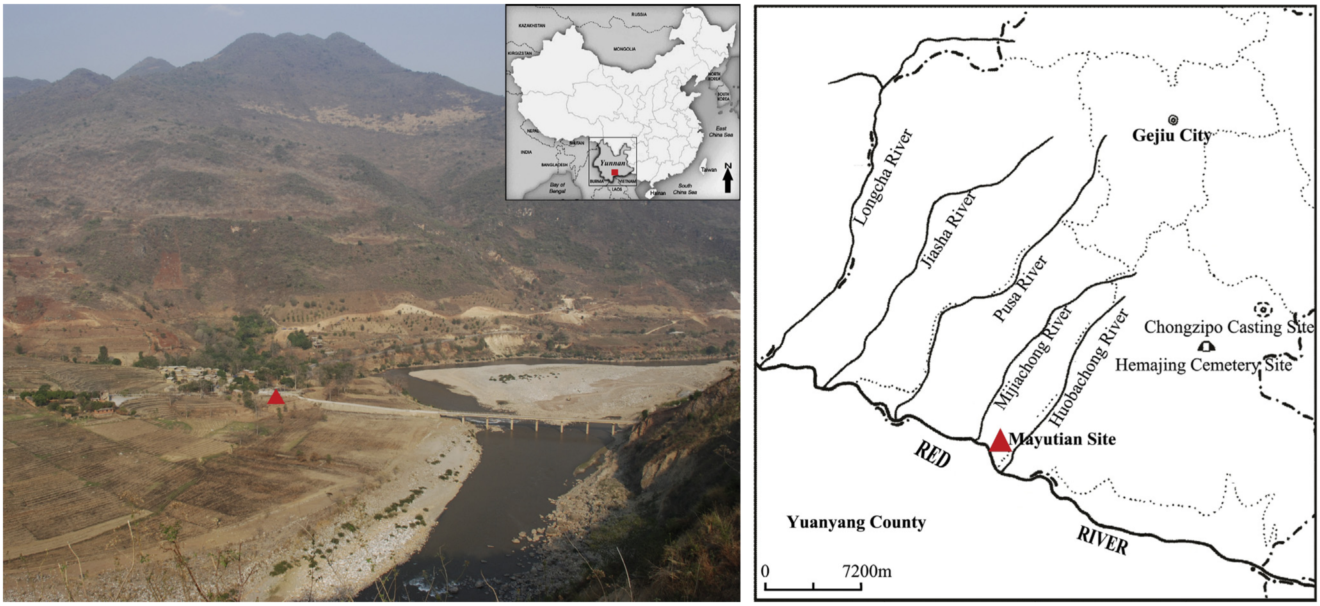

Fig. 1. The location of Mayutian (Red triangle) and adjacent rivers (modified from Yunnan Provincial Institute of Culture Relics and Archaeology et al. (2013)). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

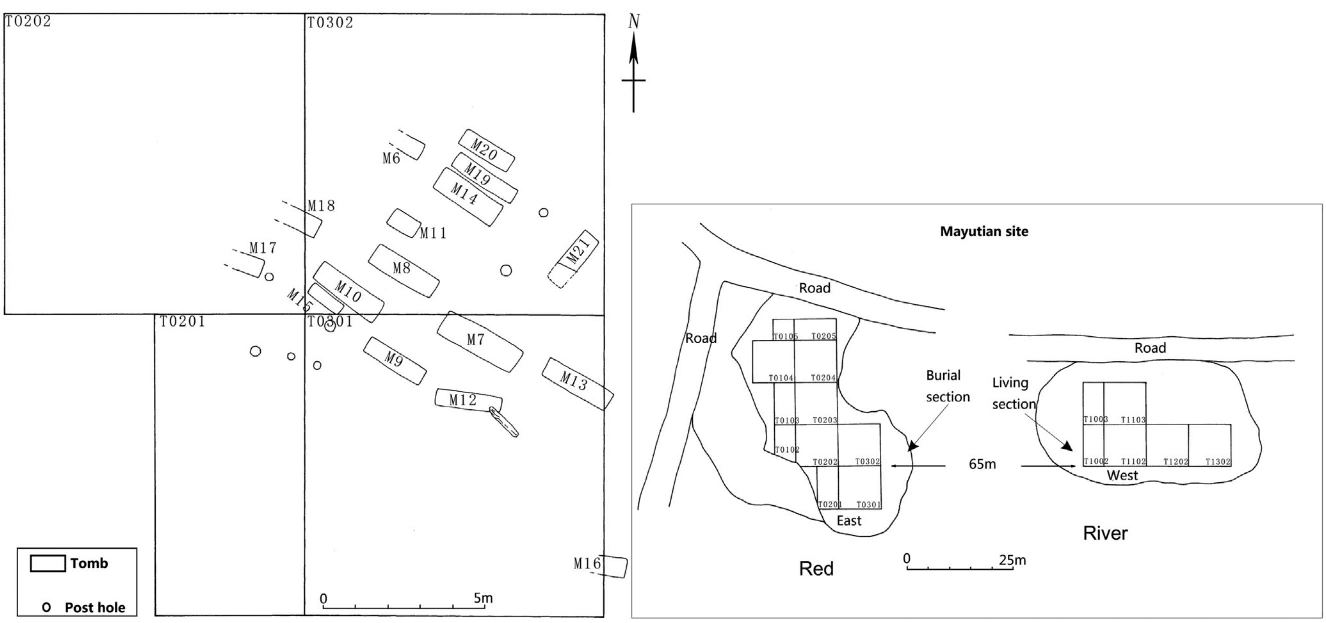

Fig. 2. The distribution of the tombs (modified from Yunnan Provincial Institute of Culture Relics and Archaeology et al. (2013)).

Dental enamel mineralizes as hydroxyapatite, $Ca_{10}(PO_4)_6(OH)_2$ during the first years of life and retains its chemical and isotopic composition throughout the life of the individual. The isotopes of strontium, carbon and oxygen in the enamel thus reflect the isotopes in the diet during childhood.

Depending on preservation and availability, all selected teeth were molars but no identification of specific molars (M1, M2 or M3) was attempted. First and second molars (M1 and M2) mineralize during early childhood; the third molar (M3) mineralizes about the age of 12 years (ElNesr and Avery, 1994; Hillson, 2005). Thus there is some uncertainty in the data of the timing of mineralization. A total of 14 tooth samples, each from a separate individual, listed in Table 2, were selected for analysis.

In contrast to enamel, bones continually remodel during life so that, for an individual who moves from one place to a new location with a different isotope pattern, the bones shift isotopically toward that of the new place of residence. Ericson (1985), in the seminal strontium isotope paper, suggested that one could compare tooth isotopes to bone isotopes to see if someone was an immigrant. While a match might be equivocal, a big difference between tooth and bone ratios would imply recent relocation. We now know that bones are easily contaminated in the post mortem-environment, so they tend to be similar to that of the burial location regardless of if or when an individual might have relocated. Nonetheless, a match between bone and tooth data can help to reinforce an assessment of what might be the local isotope

Table 1
Sample information from Mayutian.

Sample no.	Sex	Direction	Funeral objects
GMM6	?	122°	–
GMM7	?	120°	1 Ceramic vessel
GMM9	?	120°	Bronze fragments
GMM10	?	126°	1 Ceramic vessel, Copper headwear, Stone axe
GMM12	Male?	96°	1 Ceramic vessel, 1 Bronze spearhead, 1 Bronze *yue*, 1 Bronze *Cu* (plow/hoe)
GMM13	?	114°	1 Ceramic vessel, 1 Bronze arrowhead
GMM14: 3	Male ?	122°	1 Ceramic vessel, 1 Bronze spearhead 1
GMM15	Child	123°	Associated with M10
GMM16	?	98°	–
GMM17	?	126°	1 Ceramic vessel
GMM18	?	115°	1 Ceramic vessel
GMM19	Male ?	122°	1 Bronze spearhead
GMM20	?	125°	1 Ceramic vessel
GMM21	Male?	44°	2 Ceramic vessels

pattern. We were able to sample 11 of the 14 individuals listed above for strontium isotopes in bone.

2.1. Strontium

2.1.1. Principles

Strontium has three stable, non-radiogenic isotopes (^{84}Sr, ^{86}Sr and ^{88}Sr) and one radiogenic isotope (^{87}Sr), which is produced by the decay of radioactive ^{87}Rb (Faure, 1986). The ratio of ^{87}Sr to a non-radiogenic isotope, conventionally chosen as ^{86}Sr due to the similar relative abundance, varies geographically and the ^{87}Sr/^{86}Sr ratio in dental enamel reflects these geographic differences. Because the half-life of the Rb- > Sr decay process is on the order of fifty billion years, the ^{87}Sr/^{86}Sr does not change during the span of human existence, nor is it significantly fractionated by movement through food webs. The^{87}Sr/^{86}Sr ratio in dental enamel is that of the childhood diet, which parsimoniously reflects that of the local or regional geology.

Such use of strontium isotopes was first proposed by Ericson (1985) and subsequently developed by Price and colleagues in North America (e.g., Price et al., 1994a, 2000; 2008; Ezzo et al., 1997; Ezzo and Price, 2002), South America (Knudson and Price, 2007) and Europe (e.g., Price et al., 1994b, 2004; Bentley et al., 2002, 2004; Grupe et al., 1997; Sjögren et al., 2009). Now it is commonly used worldwide to assess animal as well as human mobility in both modern and prehistoric contexts.

The Red River flows along the Ailaoshan/Red River shear zone, a major tectonic discontinuity extending from Tibet to the Gulf of Tonkin (Tapponnier et al., 1990; Leloup et al., 1995). The Yuanjiang region of the Red River has metamorphic rocks of the shear zone itself, which is surrounded by Paleozoic and Mesozoic sediments (Fig. 4). Metamorphic rocks tend to have relatively high ^{87}Sr/^{86}Sr ratios, >0.712. Sedimentary rocks here comprise mainly limestone and red beds; limestones have intermediate^{87}Sr/^{86}Sr values of 0.707–0.708, although measurements as low as 0.7069 have been identified in some limestones of Permian age (Korte et al., 2006). Jiang and colleagues (Jiang et al., 2009) measured ^{87}Sr/^{86}Sr ratios in river waters, which should approximate to biologically available ratios, in southeastern Yunnan. They found values of 0.7076–0.7079 for calcitic limestone terrains and 0.7084 to 0.7096 for dolomitic limestones. Han and Liu (2004), in a study similar to that of Jiang found that, in nearby Guizhou, river waters characterized by silicate weathering have higher ratios than those dominated by carbonate (limestone) weathering. Red beds tend to be slightly high (0.711), lower than metamorphic rocks but higher than limestones. There are no low (<0.707) rocks in the Yuanjing area - the closest low ^{87}Sr/^{86}Sr rocks being the Emishan basalts, which outcrop north of Dali and have ^{87}Sr/^{86}Sr of 0.7066 ± 0.0005 (Xiao et al., 2004).

2.1.2. Procedure

For strontium isotope analysis, using an established procedure, about 7–10 mg of tooth enamel was cut from each individual with a dental drill. We mechanically cleaned any visible dirt or contamination and removed dentine with a surgical steel scalpel, and then soaked the sample for 8 h in weak (5%) acetic acid. Enamel power was then dissolved in 3N HNO_3 on a hot plate. Strontium was purified from this solution by cation exchange chromatography in Teflon columns with Eichrom Sr-spec resin and nitric acid as the mobile phase. The Sr-Spec resin was presoaked and flushed with H_2O to remove any Sr present from the resin manufacturing process. The resin was further cleaned in the column with repeated washes of 18-MegOhm MilliQ H_2O and conditioned with 3N HNO_3. Purified Sr was extracted with 3N HNO_3 acid.^{87}Sr/^{86}Sr ratios were measured on the Thermo Fisher 'Triton' at the CAS Key Laboratory of Isotope Geochronology and Geochemistry, Guangzhou Institute

Fig. 3. GMM12 human skeleton and bronze spearhead, *yue* and *hoe*.

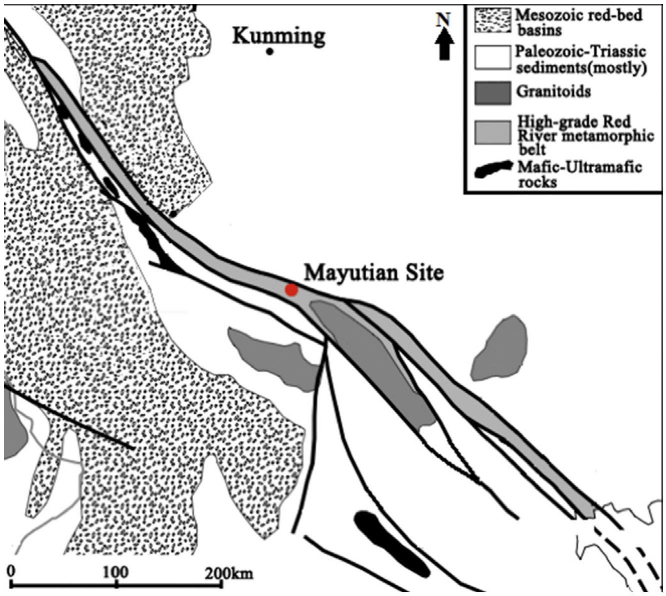

Fig. 4. Geology of the Yuanjiang section of the Red River showing the location of Mayutian. Map modified from Gilley et al. (2003) and Leloup et al. (1995).

of Geochemistry, Chinese Academy of Science (CAS-GIG). The data obtained were standardized with six replicate measurements of the NBS SRM987 standard, yielding an average $^{87}Sr/^{86}Sr$ ratio of 0.710247 ± 0.000007(2 s.d.).

2.2. Oxygen and carbon

2.2.1. Principles

Oxygen has three stable isotopes (^{16}O, ^{17}O, and ^{18}O). We focus upon the two most abundant isotopes, ^{18}O (99.8%) and ^{16}O (0.2%) because of the large relative mass difference between these, ^{18}O being 12.5% heavier than ^{16}O. Because water molecules are mainly oxygen by weight, $H_2^{18}O$ is 11% heavier than $H_2^{16}O$. Heavier water molecules are more difficult to evaporate than the lighter water molecules and, once in the atmosphere, lighter molecules remain longer than the heavier molecules. When the temperature is higher, there is more energy to keep both molecules in the air, but when the temperature is cold, the heavier molecules are preferentially removed and the remaining moisture becomes isotopically lighter. Thus the isotopic composition, and $^{18}O/^{16}O$, of rainfall varies with temperature and related environmental factors such as elevation, latitude, and distance inland. The oxygen in the hydroxyapatite of bones and teeth, measured as a part-per-mil (‰) difference, $\delta^{18}O$, between the sample and a reference standard, has been demonstrated to correlate with the $^{18}O/^{16}O$ of local precipitation (Longinelli, 1984; Luz et al., 1984; Luz and Kolodny, 1985; Sponheimer and Lee-Thorp, 1999) and thus varies geographically. Although oxygen is generally less sensitive to regional geography than strontium, oxygen isotopes have been successfully used in Mesoamerica to assess mobility among the ancient Maya (White et al., 1998, 2000; Wright, 2012).

Although carbon isotopes are not normally used to assess mobility, $^{18}O/^{16}O$ is determined by measuring the masses of $C^{13/12}O^{18/16}{}_2$ molecules liberated from the carbonate fraction of hydroxyapatite. Thus carbon $C^{13/12}$ ratios are obtained simultaneously on the same sample. $C^{13/12}$ ratios, measured like oxygen $\delta^{18}O$ as a part-per-mil difference between sample and standard,$\delta^{13}C$, provide information about the proportion of ‘C3’ and ‘C4’resourcesin the diet (Van Der Merwe and Vogel, 1978; Schoeninger and DeNiro, 1984). Most plants are ‘C3’ plants, using a three-carbon molecule during photosynthesis, but tropical grasses such as maize and millet use a different photosynthetic pathway, involving a four-carbon molecule that incorporates relatively more C^{13}. Consumers of C4 plants have higher $\delta^{13}C$ values in their hydroxyapatite carbonate as well as in their collagen.

Human enamel $\delta^{13}C_{(VPDB)}$ ranges approximately from −14‰ for purely C3 diets to approximately 0‰ for purely C4 diets (Ambrose and Norr, 1993; Koch et al., 1994). In China the major factors are the consumption of rice (C3) and millet (C4).

Table 2
Isotope values in tooth enamel and bones from Mayutian skeletons.

Sample no.	Enamel $^{87}Sr/^{86}Sr$	Bone $^{87}Sr/^{86}Sr$	$\delta^{13}C$ ‰VPDB	$\delta^{18}O$ ‰VPDB
GMM6	0.710056	–	−8.37	−7.19
GMM7	0.709727	–	−8.54	−7.36
GMM9	0.709116	0.708869	−6.70	−6.82
GMM10	0.709345	0.709148	−9.09	−6.11
GMM12	0.706675	0.709192	−10.24	−6.73
GMM13	0.709415	0.709364	−8.58	−7.23
GMM14: 3	0.709754	0.709176	−10.02	−6.70
GMM15	0.709798	0.709588	−9.39	−6.03
GMM16	0.709699	0.709924	−10.89	−6.66
GMM17	0.709301	–	−12.04	−6.05
GMM18	0.709250	0.709189	−6.33	−6.37
GMM19	0.709460	0.709342	−7.55	−6.78
GMM20	0.709977	0.709008	−10.52	−7.12
GMM21	0.709289	0.709040	−9.75	−7.29

2.2.2. Procedure

For carbon and oxygen isotopes, powdered enamel samples were prepared in the Laboratory for Archaeological Chemistry University of Wisconsin–Madison by selecting a few milligrams of finely powdered enamel, which were sent without further treatment to David Dettman at the Environmental Isotope Laboratory of the University of Arizona Department of Geosciences. $\delta^{18}O$ and $\delta^{13}C$ of tooth enamel carbonate were measured using an automated carbonate preparation device (KIEL-III) coupled to a gas-ratio mass spectrometer (Finnigan MAT 252). Powdered samples were reacted with dehydrated phosphoric acid under vacuum at 70 °C in the presence of silver foil. The isotope ratio measurement is calibrated based on repeated measurements of NBS-19 and NBS-18 and precision is ± 0.1‰ for $\delta^{18}O$ and ± 0.06‰ for $\delta^{13}C$ (1 s). The carbonate-CO_2 fractionation for the acid extraction is assumed to be identical to that of calcite.

3. Results

The isotope results are presented in Table 2, sorted by individual burial.

3.1. Strontium

The strontium results (Fig. 5) are the most revealing: dental enamel $^{87}Sr/^{86}Sr$ for all but one of the individuals cluster closely about 0.7096, with one extreme outlier at 0.7066. Removing this outlier from the calculation, the remaining set has a mean value of 0.70955 ± 0.00030. Parsimoniously this is the regional ratio for the Yuanjiang region, suggesting that all except the outlier are either local or from an area that cannot be isotopically distinguished from the local range.

It is significant that the one outlier, GMM12, is the highest status individual as determined by grave goods. The distinct $^{87}Sr/^{86}Sr$ difference clearly indicates that this individual cannot be of local (or regional) origin. GMM12's ratio of 0.7066 is in the low end of the isotope range for humans and is inconsistent with a geographic origin in a region of either metamorphic or sedimentary geology, i.e. within a few hundred km of Mayutian. The closest low $^{87}Sr/^{86}Sr$ values are found in the Emishan basalts north of Dali, which is also

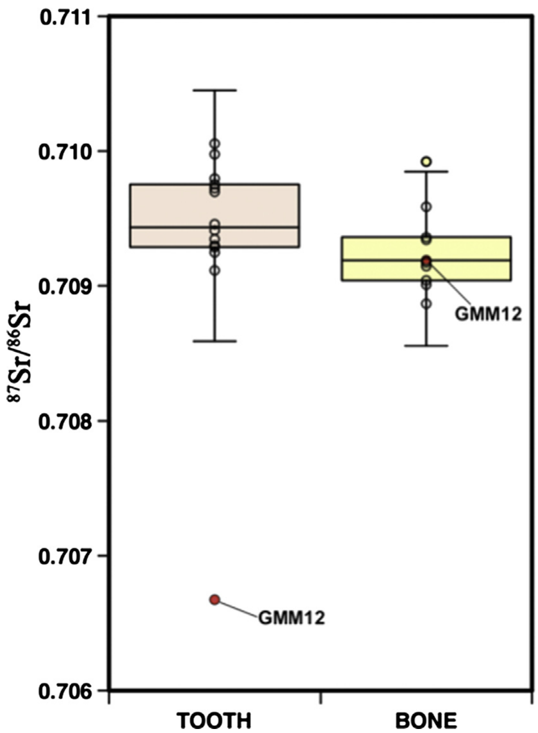

Fig. 5. Box plot of $^{87}Sr/^{86}Sr$ for Mayutian samples, with individual data points shown. Note the tooth value for GMM12 is an extreme outlier.

located in the Ailaoshan shear zone. The GMM12 ratio of 0.7066 matches well the mean value of 0.7066, obtained by Korte et al. (2006) from the basalts. We suspect this is the geographic origin of GMM12. As part of our plan to isotopically characterize this region, we plan future analyses of human remains from the area north of Dali to further evaluate this hypothesis.

The bone strontium values similarly cluster about 0.7093 and include the bone from GMM12. The similarity between the range for the bones and the range for the teeth add support that the tooth range is indeed the local range for Mayutian. The slight offset of 0.003 between the tooth average (0.7096) and the bone average (0.7093) is consistent with diagenetic alteration of bone within the burial environment. While the tooth to bone shift for GMM12 is consistent with a long residence at Mayutian after moving from another location, the local value exhibited by the bone could likewise be the result of this diagenetic contamination and should not be accepted as strong evidence of time of residence.

3.2. Oxygen

Oxygen isotopes average $-6.75 \pm 0.46‰$ and range from $-7.36‰$ to $-6.03‰$ $\delta^{18}O_{(VPDB)}$. This is an unusually low range – intrinsic physiological variation can produce a range $>1.5‰\delta^{18}O$ (White et al., 2000) within a single individual. Although this means that oxygen data do not reveal outliers that could be immigrants, it is interesting to note that GMM12 enamel $\delta^{18}O_{(VPDB)}$ does not differ significantly from the $\delta^{18}O_{(VPDB)}$ of the other teeth. This suggests that the home region for GMM12 does not differ enormously in temperature, climate, or distance inland, consistent with a relatively nearby origin in the northwest, but not with migration from a great distance.

3.3. Carbon

Carbon $\delta^{13}C_{(VPDB)}$ data average $-9.14 \pm 1.6‰$, ranging from $-12.04‰$ to $-6.33‰$. These are slightly on the lighter side of the midrange of carbon isotopes, indicating a mixed diet from both C3 and C4 sources. This implies that at Mayutian neither rice nor millet agriculture dominated the subsistence strategy.

4. Conclusions

The local $^{87}Sr/^{86}Sr$ value for humans from the Yuanjiang region is 0.7096 ± 0.0003.

$^{87}Sr/^{86}Sr$ for the highest status individual, GMM12, is an extreme outlier, indicating this individual was born outside the Mayutian region. Comparison with regional geologic and isotopic data suggests this individual may have come from the head water area of the Yuanjiang valley or further north such as the northwest in the vicinity of Dali.

Stable isotopes are consistent with a mixed C3–C4 diet and are inconsistent with an agricultural strategy dominated by either rice (C3) or millet (C4).

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